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(54) **VEHICLE ENGINE COOLING SYSTEM WITH VARIABLE SPEED WATER PUMP**

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(52) **U.S. Cl.** .... **123/41.44**; 123/198 C; 123/41.46

(58) **Field of Search** .... 123/41.44, 41.46, 123/41.47, 41.49, 198 C

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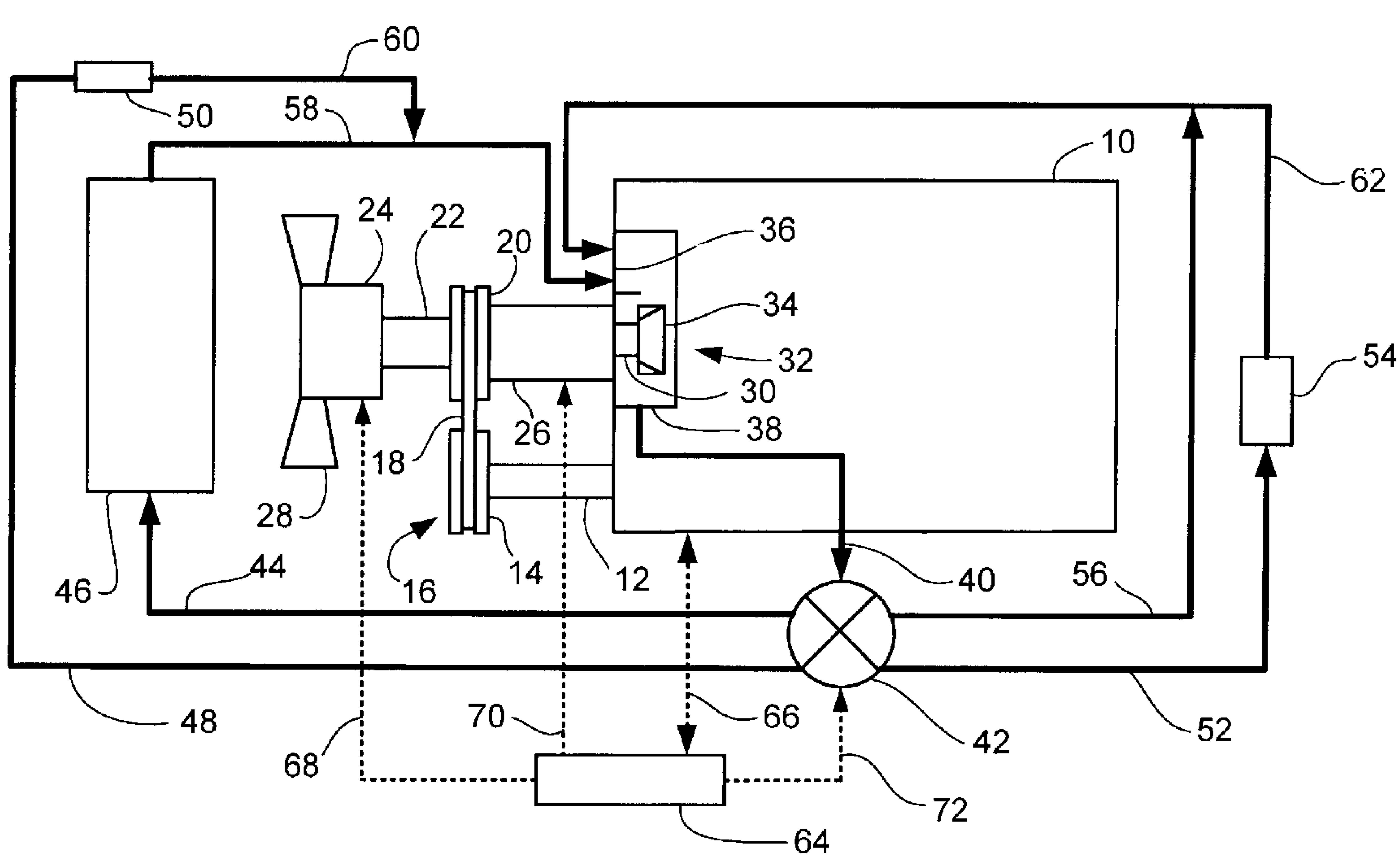
(57) **ABSTRACT**

An engine cooling system and method that will allow an engine water pump to be driven independently of the engine speed. The engine water pump is driven by the engine crankshaft, but includes an electronically controllable pump clutch between the water pump and the crankshaft. A control module electronically controls the engagement of the pump clutch based upon engine and vehicle operating conditions.

18 Claims, 3 Drawing Sheets



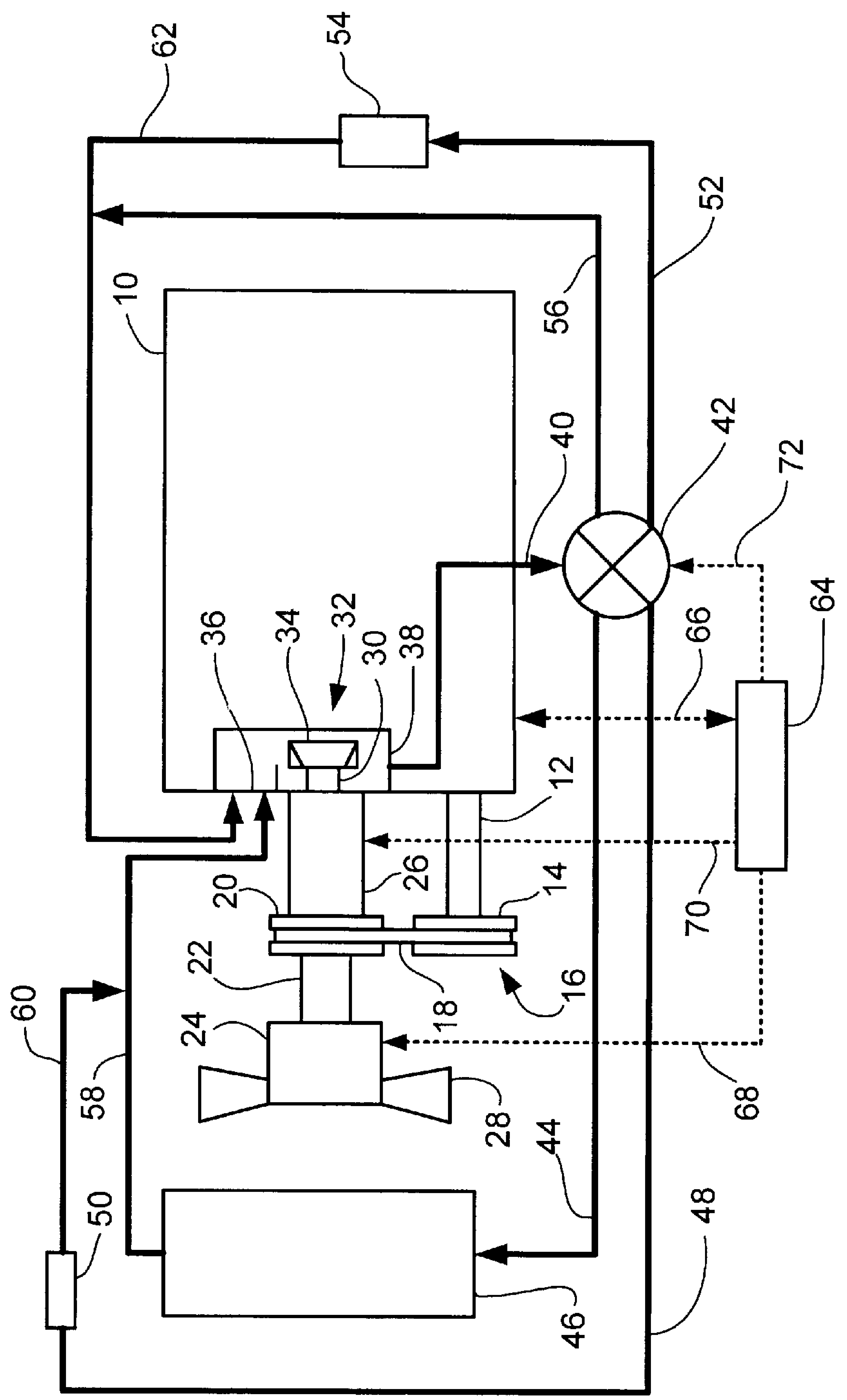

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Fig. 1

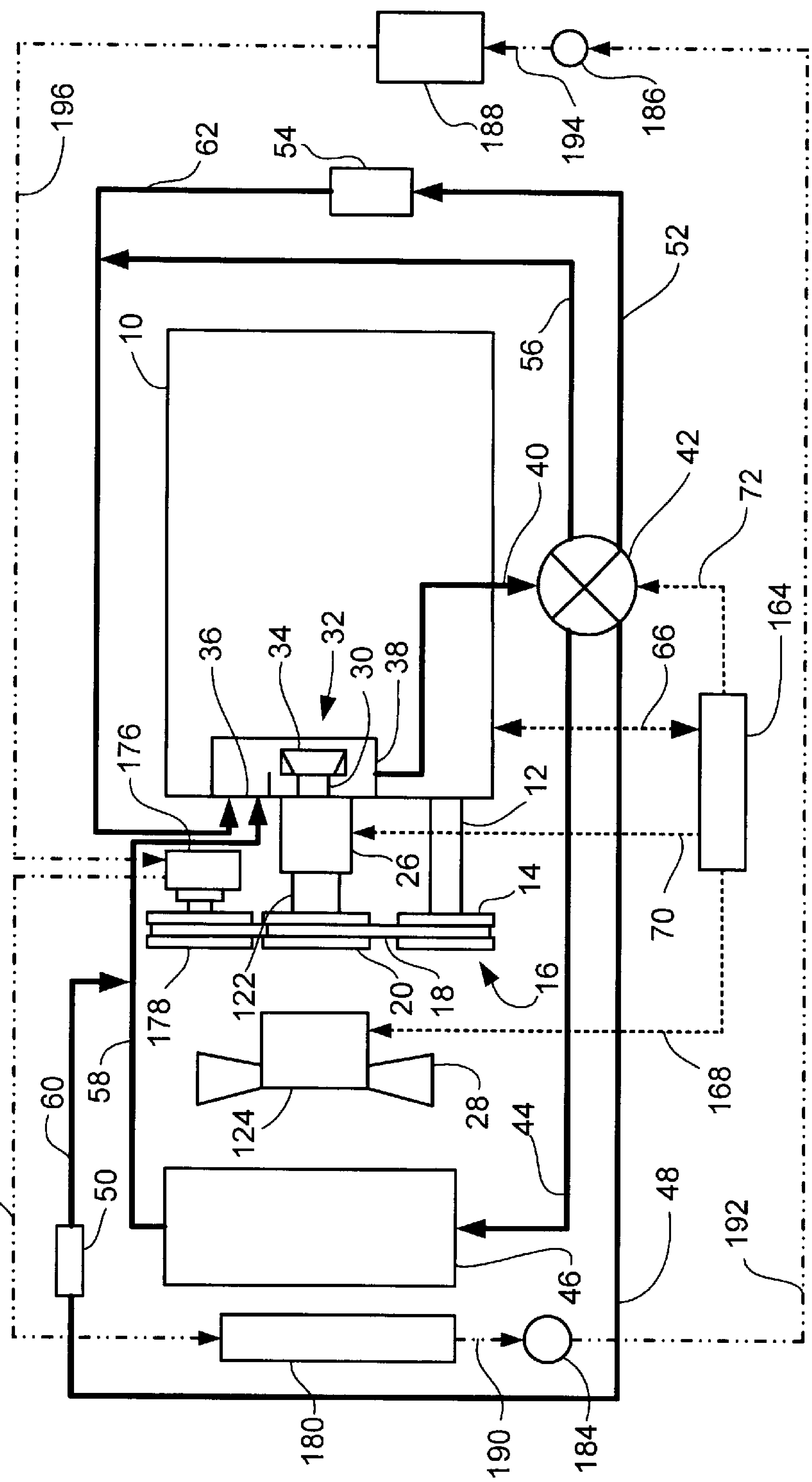
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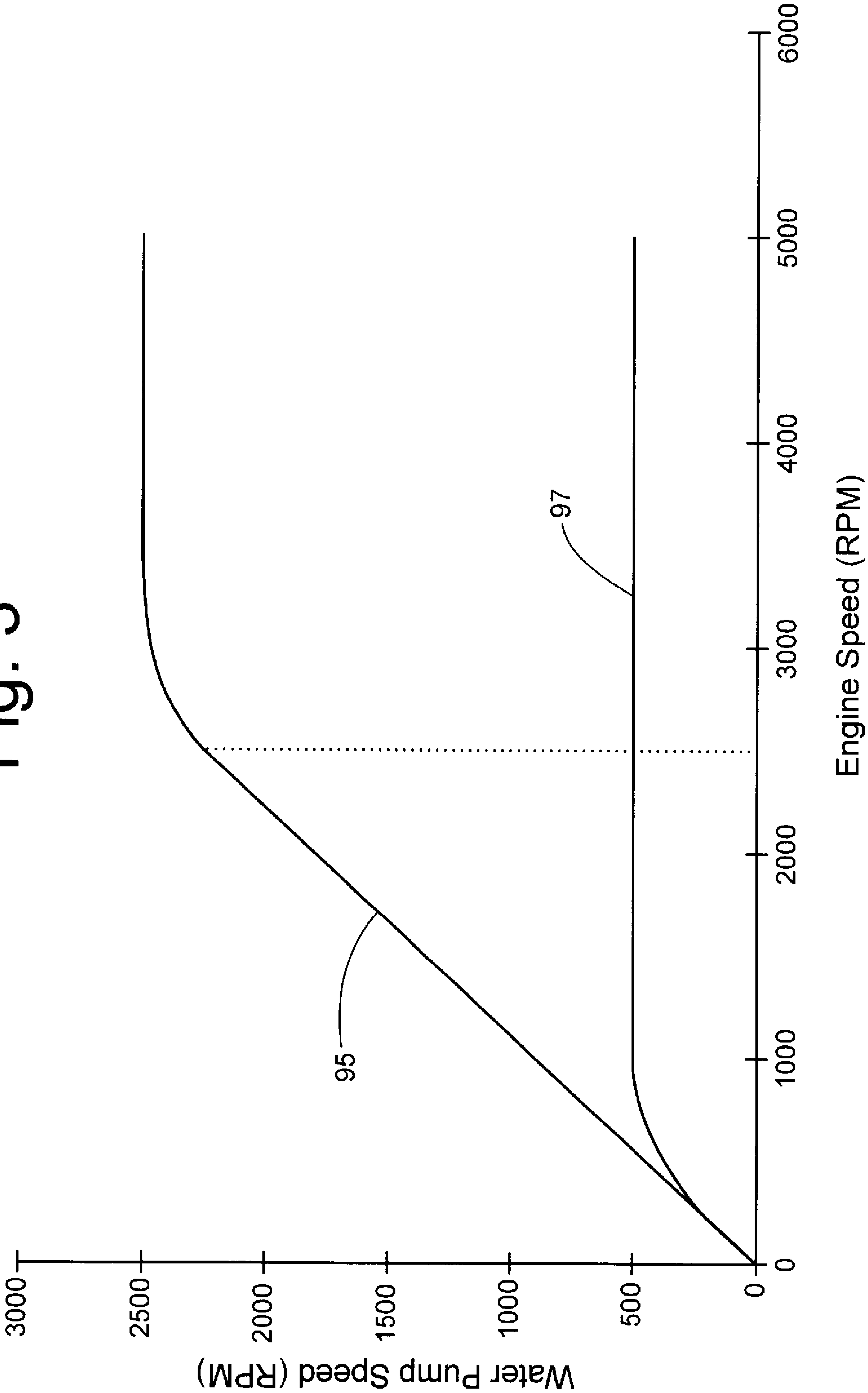
Fig. 2

Fig. 3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0
500
1000
1500
2000
2500
3000
Engine Speed (RPM)
0
1000
2000
3000
4000
5000
6000
95
97

VEHICLE ENGINE COOLING SYSTEM WITH VARIABLE SPEED WATER PUMP

BACKGROUND OF INVENTION

The present invention relates to a cooling control system and a cooling control method for cooling an engine of, for example, a vehicle.

Conventionally, in a vehicle engine, a cooling circuit employing a radiator is used to remove excess heat from the engine, maintain a constant operating temperature, increase the temperature in a cold engine quickly, and heat the passenger compartment. The cooling circuit includes a coolant, which is typically a mixture of water and anti-freeze (such as ethylene glycol). The cooling circuit includes a water (i.e. coolant) pump that is powered via the crankshaft of the engine, usually through a pulley and belt assembly or gear set connected between the crankshaft and the pump, so its speed varies with the speed of the engine. The water pump is typically an impeller or centrifugal pump that forces coolant through the engine, hoses, radiator, and other system components. Also, when it is desirable to heat the passenger compartment, it pumps coolant through a heater core. When the engine is started cold, the coolant is below the optimum temperature for engine operation and it does not contain enough heat for transferring to the passenger compartment. In order to more quickly warm up such an engine system, then, a thermostat is used to restrict the flow of coolant to the radiator until the coolant is up to the desired temperature range. Once up to temperature, the coolant is routed through the radiator to assure that the temperature is maintained in the desirable range, and can be routed through the heater core to heat the passenger compartment.

One drawback to conventional water pump systems is that the flow rate of coolant is controlled by engine speed, not by the amount of cooling that the cooling system needs. Therefore, there is no way to optimize engine thermal management using a mechanical water pump alone. For example, when an automobile leaves a highway and enters city traffic, the engine speed and radiator cooling capability may not be adequate to cool the engine block in a timely manner. This could result in damage to vital engine components. Consequently, while this conventional type of cooling system is straight forward and relatively easy to implement, it is not very good at providing the optimum cooling for the particular engine and vehicle operating conditions—particularly since the water pump is only a function of the engine speed, not any other factors important to maintaining the desired coolant temperature.

In order to improve the heat transfer efficiency of the radiator, these conventional types of systems also employ an engine fan, mounted adjacent to the radiator, to draw air through the radiator in order to better cool the coolant. The radiator fan is typically powered via the pulley driving the water pump or an electric motor. The pulley driven fan suffers from the same drawbacks as the pulley driven pump, while the motor driven fan, even though it operation is more flexible, adds to the electrical power load on the vehicle.

More recently, advanced engine cooling systems have been developed that will more precisely control the engine cooling. A more advanced system may be, for example, a system and method as described in U.S. Pat. No. 6,374,780, assigned to the assignee of this application, and incorporated herein by reference. These newer systems take into account additional factors that influence both what the desired coolant temperature is and how it is achieved. Such a system

might include a radiator that receives the coolant flowing out of the engine, cools the coolant and returns it to the engine; a bypass circuit for making the coolant flowing out of the engine bypass the radiator when the coolant is below the desired temperature; a fan that is driven by a motor so that its speed can be controlled to be optimum for the particular engine and vehicle conditions (independent of the engine speed); an electronically controlled flow rate control valve (or valves) for regulating the percentage of coolant bypassing the radiator; and a water pump that is either conventionally driven via the crankshaft or by an electric motor, with the pumping rate of the electric motor controlled water pump precisely controlled to provide a desired coolant flow rate for the particular engine and vehicle operating conditions. Thus, the engine cooling system can be precisely controlled and the heating, ventilation and air conditioning (HVAC) performance optimized by controlling the coolant mass flow rate, the air mass flow rate, and the coolant flow path by one overall control strategy.

However, these advanced engine cooling systems have a drawback in that they require substantially more electric power consumption than the conventional systems. The electrically controlled valve, electrically controlled Water pump, and when employed, the electrically controlled fan all draw additional electrical power. Moreover, many additional electronic components are typically found on modern vehicles, which pushes the limit on the electrical current available from the vehicle charging system. This is particularly a concern with vehicle charging systems employing a conventional 12V electrical system rather than a high voltage system, such as 42 volts. And, in particular, pick-up trucks, sport utilities and other larger vehicles in the light vehicle class that run on 12 volts require more electrical power for the fan and water pump than typical passenger cars, so the current draw is even greater.

Thus, it is desirable to have an engine cooling system that overcomes the drawbacks of the conventional systems, while minimizing the additional electrical power needed to operate this system.

SUMMARY OF INVENTION

In its embodiments, the present invention contemplates a cooling system for controlling the temperature of an engine, with the engine having a rotating member. The cooling system includes a radiator, and an accessory drive adapted to be driven by the rotating member. The system also includes a pump clutch having an input member operatively engaging the accessory drive and an output member selectively engagable with the input member, and with the pump clutch electronically controllable to select the amount of engagement between the input member and the output member. A water pump is adapted to pump water through the engine and the radiator, with the water pump operatively engaging the output member to be driven thereby. Also, a controller operatively engages the pump clutch to thereby adjust the amount of engagement between the input member and the output member according to predetermined operating conditions.

The present invention further contemplates a method of cooling an engine, having a rotating member and a radiator, in a vehicle, the method comprising the steps of: driving an accessory drive with the rotating member; driving a water pump clutch input shaft with the accessory drive; monitoring predetermined engine and vehicle operating conditions; selectively changing the degree of engagement of a water pump clutch output shaft with the water pump input shaft based on the engine and vehicle operating conditions; and driving a water pumping mechanism with the water pump clutch output shaft.

An embodiment of the present invention provides a system that automatically adjusts the flow rate through the engine cooling system via a viscously clutched water pump driven off of the engine. The flow path can be adjusted via an electronically controlled flow control valve, and further thermal management can be obtained via an electronically controllable engine fan.

An advantage of the present invention is that a viscous clutched water pump reduces the electrical power draw from that of a motor driven pump, allowing an advanced engine cooling system to be employed without the need to greatly increase a vehicle charging system capacity.

Another advantage of the present invention is that the water pump speed can be controlled independent of the engine speed (below pulley speed).

An additional advantage of the present invention is that the pump clutch is configured so that the clutch fully engages if the power to the clutch is lost. This allows for a fail safe to ensure that engine damage due to overheating will not occur if electrical power to the pump clutch is lost.

Still another advantage of the present invention is that the overall efficiency of the clutched, engine driven water pump is higher than an electric motor driven pump due to the higher losses in conversion of mechanical energy into electrical energy by the vehicle alternator, and the conversion of electrical energy into mechanical energy by the electric water pump motor.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a schematic diagram of an engine and cooling system in accordance with the present invention;

FIG. **2** is a diagram similar to FIG. **1**, but illustrating al alternate embodiment of the present invention; and

FIG. **3** is a graph illustrating an example of the engine speed versus the water pump speed depending upon the amount of clutch engagement.

DETAILED DESCRIPTION

FIG. **1** illustrates an engine **10**, which may be employed for example in a vehicle. The engine includes a crankshaft **12**, which not only provides power for locomotion of the vehicle, but is also connected to a crankshaft pulley **14** of a front end accessory drive **16**. The crankshaft pulley **14** is coupled to a drive belt **18**. The drive belt **18** is also coupled to a driven pulley **20** of the front end accessory drive **16**. While a pulley and belt assembly is shown, a different assembly for transferring torque, such as, for example, a gear set may also be employed.

The driven pulley **20** is mounted on an input shaft **22**. The input shaft **22** is connected at one end to an input to an electronically controlled viscous clutch **24** for a fan and at its other end to an electronically controlled viscous clutch **26** for a pump. While the clutches are preferably viscous clutches (clutches that transfer torque by shearing a fluid), other types of electronically controllable clutches that are generally continuously variable between the engaged and disengaged states can also be employed. An output to the fan clutch **24** connects to and drives a set of fan blades **28**. An output to the pump clutch **26** connects to and drives a water pump shaft **30** of a water pump **32**, with the shaft **30** connected to a water pump impeller **34**.

The pump **32** includes an inlet **36** and an outlet **38**. The outlet **38** connects to flow passages in the engine **10**, which then connect to a coolant passage **40** leading to an inlet of an electronically controlled, four-way valve **42**. The coolant passages are illustrated herein by heavy lines with arrows indicating the direction of the coolant flow. The four way valve has four outlets to which the inlet can selectively connect. A first outlet leads through a radiator coolant inlet passage **44** to a radiator **46**, a second outlet leads through a degas coolant inlet passage **48** to a degas container **50**, a third outlet leads through a heater coolant inlet passage **52** to a heater core **54**, and a fourth outlet leads through a by-pass coolant passage **56**.

The radiator **46** also connects to a radiator coolant outlet passage **58** that leads to the water pump inlet **36**. The degas container **50** also connects to a degas coolant outlet passage **60** that leads to the radiator coolant outlet passage **58**. A heater coolant outlet passage **62** extends from the heater core **54** to the water pump inlet **36**, with the by-pass coolant passage connecting to the heater outlet passage **62**.

A control module **64** is electrically connected to the engine cooling system in order to monitor and control the engine cooling process. The control module **64** communicates with various subsystems on the engine **10** through various electrical connections **66**. The electrical connections are illustrated herein by dashed lines. The control module **64** also has an electrical connection **68** to the fan clutch **24**, an electrical connection **70** to the pump clutch **26**, and an electrical connection **72** to the four way valve **42**.

The engine cooling system controls the fan blades **28** by the control module **64** regulating the fan clutch **24**. The crankshaft **12** transfers torque to the crankshaft pulley **14**, which, in turn transfers torque to the driven pulley **20** through the drive belt **18**. The driven pulley **20** transfers the torque to the input shaft **22**. The input shaft **22** transfers torque to the input to the fan clutch **24**. The fan clutch **24** includes an input and an output (not shown), with a viscous shear fluid between the two. The control module **64** opens and closes a valve (not shown) in the clutch **24**, with the valve controlling the level of viscous shear fluid between the input and output clutch plates. Depending upon the fluid level, there may be very little or no torque that is transferred from the input to the output, so the fan blades **28** are not driven off of the pulley **20**, or a large torque transfer, thus driving the fan blades **28** up to the speed of the pulley **20**. The amount of electrical power transferred from the control module **64** to the fan clutch **24** does not have to be large since this power is only needed to control the valve—the actual torque driving the fan blades **28** is produced by the engine **10**.

This configuration allows for continuously variable fan speed at or below the driven pulley speed. So, by controlling the fan clutch **24**, the fan speed can be maintained at the desired rotational velocity, even with variations in engine speed. In order to assure that the desired fan speed can be maintained for the various engine and vehicle operating conditions, the pulley ratio can be set so that the necessary fan speed (and water pump speed) can be achieved throughout the desired engine operating range. Further, the fan blades **28** can be stopped when it is undesirable to draw additional air through the radiator **46**. The control strategy for the fan **28** is preferably not an open loop correlation, like that typically employed with a motor driven fan, since it may be desirable to have the fan **28** run at a particular speed even with variations in engine speed. Consequently, the control module **64** will require an engine speed input in addition to the inputs that determine the desired fan speed for engine cooling.

The engine cooling system controls the pump impeller **34** by the control module **64** regulating the pump clutch **26**. The crankshaft **12** transfers torque to the crankshaft pulley **14**, which, in turn transfers torque to the driven pulley **20** through the drive belt **18**. The driven pulley **20** transfers the torque to the input shaft **22**. The input shaft **22** transfers torque to the input to the pump clutch **26**. The pump clutch **26** includes an input and an output, with a viscous shear fluid between the two. The torque transfer is a function of the surface area over the shear thickness. The input and output are biased toward one another such that, when the control module **64** supplies no electrical power to the pump clutch **26**, the shear thickness will be a minimum—so maximum torque is transferred from the input to the output, with the pump impeller **34** rotating at essentially the driven pulley speed. The full clutch engagement is illustrated by the portion of line **95** (FIG. **3**) below an engine speed of about 2500 RPMs. There is an additional, optional control strategy that may be employed with the fan clutch **24**. When the engine speed is at or above a certain threshold (for example about 2500 RPMs, as shown in FIG. **3**), the control module **64** will signal the pump clutch **26** to disengage partially so that the impeller **34** does not spin above a predetermined maximum. This predetermined maximum is a function of the saturation limit of the radiator **46**. In this way, the performance versus power consumption is optimized at the high engine speeds. This is illustrated by the portion of line **95** above an engine speed of about 2500 RPMs.

On the other hand, when the control module **64** supplies power to the pump clutch **26**, coils are energized that open an internal valve, forcing more fluid between the input and output. The input and output are pulled farther apart, so the viscous shearing of the fluid will transfer less torque. The higher the power supplied, the farther the input and output are pulled apart, and so the lower the torque transfer. The control module **64** is programmed to disengage the pump clutch **26** to a point where the water pump **32** is pumping some predetermined minimum amount of water through the engine **10** so that, even if the coolant temperature is low, the coolant will flow enough to assure that no damage causing hot spots will occur within the engine **10**. This minimum water pump speed is shown as line **97** in FIG. **3**.

The pump clutch **26** operates the opposite of the fan clutch **24** so that, should the control module **64** fail to signal the pump clutch **26**, the pump **32** will still force water through the system in order to assure that the engine **10** does not overheat. Once again, the amount of electrical power transferred from the control module **64** does not have to be large since this power is only needed to pull the input and output farther apart—the actual torque driving the pump impeller **34** is produced by the engine **10**. Also, one will note that, while the fan blades **28** and water pump impeller **34** are driven by the same input shaft **22**, the output speed of each can be independently controlled.

The operation of the engine cooling system will now be described. The control module **64** monitors and adjusts the engine temperature by using multiple inputs from an engine control system, and other sensors to constantly minimize the current temperature error from the currently desired operating temperature. The factors for determining the current desired engine temperature may be the engine load, ambient environmental conditions, passenger compartment heat demand, and the other vehicle operating conditions, such as, for example, air conditioning head pressure, ambient air temperature, vehicle speed, heater demand in the passenger compartment, throttle position, engine speed, and ignition key position. The particular engine temperature being targeted may be coolant temperature or cylinder head temperature, as is desirable for the particular engine cooling system.

Preferably, the control module **64** uses a hierarchy to minimize the overall energy consumption of the cooling system while achieving and maintaining the currently desired operating temperature. For example, if the engine temperature is too high, the control module **64** first adjusts the flow control valve **42** to provide more flow to the radiator **46**. Then, if needed, it will increase the speed of the water pump **32** by reducing power to the pump clutch **26**. And finally, if still more cooling is needed, the control module **64** will increase the speed of the fan **28** by increasing power to the fan clutch **24**. Generally, the fan **28** is only employed when the water pump cooling capability is at its maximum since the fan **28** is not as efficient at removing heat (per energy input to the fan assembly) as is the water pump **32**. The position of the flow control valve **42**, and hence the routing of the coolant, is controlled by signals from the control module **64**. The valve **42** controls the percentage of coolant transferred through the radiator **46**, by-pass line **56**, degas container **50**, and heater core **54**.

For engine cooling operation when the coolant temperature is too low, such as with a cold start, for example, the control module **64** will bring the engine temperature up quickly by energizing the pump clutch **26** to minimize the coolant flow, adjusting the flow control valve **42** to send the coolant through the by-pass **56** rather than the radiator **46**, and de-energizing the fan clutch **24** in order to stop the fan. Thus, an overall control of the engine temperature and heating system control can be obtained while minimizing the additional electrical load on the vehicle electrical system.

FIG. **2** illustrates an alternate embodiment of the present invention. Since most of the components are unchanged from the first embodiment, these are referred to by the same element numbers—only the modified or added elements are given **100**-series reference numbers. In this embodiment, the fan blades **28** are driven by an electric motor **124**, which is controlled by the control module **164** via electrical connection **168**. While this configuration will have more overall electrical power draw than the first embodiment, it provides for additional control over the fan operation. This embodiment also illustrates a vehicle that includes an air conditioning system. This system has a refrigerant compressor **176**, driven by the crankshaft pulley **14** via a compressor pulley **178**. The compressor **176** connects to a condenser **180**, via a refrigerant line **182**. In FIG. **2**, refrigerant lines are illustrated as dot-double-dash lines. The condenser **180** is mounted adjacent to the radiator **46** so that air drawn through the radiator **46** by the fan **28** will also be drawn through the condenser **180**. The refrigerant system also includes a receiver/dryer **184**, expansion valve **186**, and evaporator **188**, connected by refrigerant lines **190**, **192**, **194** and **196** respectively.

The operation of this engine cooling system is very similar to that in the first embodiment, with two main differences. First, the control module **164** will send increasing power to the fan motor **124** to increase the fan speed. Also, the control module **164** may start the fan **28**, when needed for the air conditioning system condenser **180**, even though the fan **28** is not needed at that time for engine coolant cooling. The control module **164** can then adjust the water pump speed and/or the flow control valve **42** to account for the increased cooling effect of the fan **28** on the engine coolant. In addition, the fan motor **124** can be energized after the engine **10** is turned off in order to provide additional cooling if the engine is very hot when it is turned off.

While certain embodiments of the present invention have been described in detail, those familiar with the art to which this invention relates will recognize various alternative designs and embodiments for practicing the invention as defined by the following claims.

What is claimed is:

1. A cooling system for controlling the temperature of an engine, with the engine having a rotating member, the cooling system comprising:

a radiator;

an accessory drive adapted to be driven by the rotating member;

a pump clutch having an input member operatively engaging the accessory drive and an output member selectively engagable with the input member, and with the pump clutch electronically controllable to select the amount of engagement between the input member and the output member;

a water pump adapted to pump water through the engine and the radiator, with the water pump operatively engaging the output member to be driven thereby; and

a controller operatively engaging the pump clutch to thereby adjust the amount of engagement between the input member and the output member according to predetermined operating conditions.

2. The cooling system of claim **1** wherein the input member of the pump clutch is engagable with the output member through viscous shear.

3. The cooling system of claim **1** further including an engine fan located adjacent to the radiator and having a fan input shaft; and an electric motor connected to the fan input shaft, and with the electric fan motor electrically connected to the controller to be driven thereby.

4. The cooling system of claim **1** wherein the engine includes a coolant outlet; and wherein the cooling system further includes a flow control valve having an inlet adapted to be in fluid communication with the coolant outlet of the engine, a first outlet in fluid communication with the radiator, a second outlet adapted to be in fluid communication with the engine, and a flow director for selectively controlling the degree of fluid communication between the flow control valve inlet and the first and second outlets, and with the flow director electrically connected to the controller to be controlled thereby.

5. The cooling system of claim **4** wherein the flow control valve includes a third outlet that is selectively in fluid communication with the flow control valve inlet through the flow director; and wherein the cooling system further includes a heater core in fluid communication with the third outlet.

6. The cooling system of claim **4** wherein the flow control valve includes a fourth outlet that is selectively in fluid communication with the flow control valve inlet through the flow director; and wherein the cooling system further includes a degas container in fluid communication with the fourth outlet.

7. The cooling system of claim **1** wherein the input member and the output member of the pump clutch are adapted to be substantially fully engaged when the controller does not actuate the pump clutch.

8. The cooling system of claim **1** wherein the controller adjusts the engagement of the input member relative to the output member based upon a desired speed of the pump relative to an engine speed.

9. The cooling system of claim **1** wherein the rotating member is an engine crankshaft.

10. A cooling system for a liquid cooled engine having a rotating member, the cooling system comprising:

a flow control valve having a valve inlet adapted to receive coolant from the engine, and a first valve outlet, a second valve outlet and a third valve outlet, with the valve controllable to control the degree of fluid communication between the valve inlet and each of the first, second and third valve outlets;

a water pump having a pump inlet for receiving coolant and a pump outlet for pumping coolant through the cooling system;

radiator having a radiator inlet for receiving coolant flowing out of the first valve outlet, and a radiator outlet for returning the coolant to the pump inlet;

a coolant bypass connected between the second valve outlet and the pump inlet;

a heater core having a heater inlet for receiving coolant from the third valve outlet, and a heater outlet for returning coolant to the pump;

an accessory drive adapted to be driven by the rotating member;

a pump clutch having an input member operatively engaging the accessory drive and an output member selectively engagable with the input member, and with the pump clutch electronically controllable to select the amount of engagement between the input member and the output member;

a water pump adapted to pump water through the engine and the radiator, with the water pump operatively engaging the output member to be driven thereby; and

a controller operatively engaging the pump clutch to thereby adjust the amount of engagement between the input member and the output member according to predetermined operating conditions.

11. The cooling system of claim **10** further including a degas container having an inlet and an outlet for returning coolant to the pump; and wherein the flow control valve includes a fourth valve outlet for directing fluid to the degas container inlet whereby the controller will control the degree of fluid communication between the valve inlet and the fourth valve outlet.

12. The cooling system of claim **10** wherein the input member of the pump clutch is engagable with the output member through viscous shear.

13. The cooling system of claim **12** wherein the input member and the output member of the pump clutch are adapted to be substantially fully engaged when the controller does not actuate the pump clutch.

14. A method of cooling an engine, having a rotating member and a radiator, in a vehicle, the method comprising the steps of:

driving an accessory drive with the rotating member;

driving a water pump clutch input shaft with the accessory drive;

monitoring predetermined engine and vehicle operating conditions;

selectively changing the degree of engagement of a water pump clutch output shaft with the water pump input shaft based on the engine and vehicle operating conditions; and

driving a water pumping mechanism with the water pump clutch output shaft.

15. The method of claim **14** wherein the step of selectively changing the degree of engagement includes: selecting a predetermined minimum water pump output shaft speed for particular engine operating conditions; and changing the degree of engagement, when required, to assure that the water pump output shaft speed is at least as great as the predetermined minimum water pump shaft output speed.

16. The method of claim **15** wherein the step of selectively changing the degree of engagement includes: selecting a predetermined maximum water pump output shaft speed, and changing the degree of engagement, when required, to assure that the water pump output shaft speed is less than the predetermined maximum water pump shaft output speed.

17. The method of claim **14** wherein the step of selectively changing the degree of engagement includes: selecting a predetermined maximum water pump output shaft speed, and changing the degree of engagement, when required, to assure that the water pump output shaft speed is less than the predetermined maximum water pump shaft output speed.

18. The method of claim **14** wherein the step of selectively changing degree of engagement of the water pump output shaft includes: engaging the water pump output shaft with the water pump input shaft through a viscous shearing of fluid.

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